

Assessment of Risk and Hazard of Technological Emergencies with GIS (on the Example Vinnytsia Region)

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Abstract. The paper considers the questions of assess risks and hazards of technological emergencies in case of Vinnytsia region by using GIS technology. Approaches to the definition of risk and its quantification, the scheme of the main stages of risk assessment were studied. Approaches to the organization structure of the geographic database for the management and evaluation of technological risks were developed and tested, the methodology of integrated assessment of technological risks on major regional and administrative levels with the help of GIS-modeling were developed, the largest technological risks and hazards in the Vinnytsia region and the specifics of their spatial distribution were identified.

Keywords: GIS, assessment, technological emergencies.

1. Introduction and objectives

Life safety of the population is key factor for sustainable development of society. Therefore, the GIS study of spatial characteristics distribution of risks is an important means of geographic forecasting to prevent emergency situations on the territory of Ukraine, where there was one of the worst disasters of humanity - the Chernobyl disaster. The current systems GIS-mapping is based on the development of distributed geographic databases that form the basis for the production atlases, sets of maps or the design of GIS. Modeling of geographic databases for assess the technological risks in the territory of Ukraine is one of the important directions of this research. Studying technological risks determined by the set of factors that influence the occurrence of technological emergencies. The social activities and human factors management of complex technological systems are in first place in the determination of the spatial component of the technological risks.

The number of industrial accidents is growing last years in Ukraine. This is due to high depreciation of industrial equipment, technology obsolescence, low investment in the development and updating of industrial and municipal infrastructure.

Today, the problem of assessment of natural and technological hazards and risks of emergency situations using GIS technologies is studied by many researchers using different methodological and technical approaches. Development of common European approach to risk assessment is presented in the works of European Environment Agency (2003) and ESPON (2005). The theoretical aspects of the risk assessment are developed in the works by Ferrier & Haque (2003), Bartels & van Beurden (1998), Konecny, Zlatanova, Bandrova (2010). American school of risk assessment, including the use of tools by ESRI, provides a wide range of applied cartographic research of natural and technological hazards (Bedford & Cooke 2001, Monmonier 1997, NRC 2007, Van Westen et al. 2002). Many papers about simulation of technological risk are published in recent years (Choi et al. 2004, Zhang et al. 2002). Regional aspect of the risk assessment has been studied based on the work Borst (2006), Lari (2009). In Ukraine, the risk assessment and management at the regional level with the use of GIS technology is just beginning to develop. Therefore there is a need to develop methods of risk analysis, taking into account local specifics of territory and organization of information databases.

The purpose is to assess the technological risks and dangers emergencies in case study of the Vinnytsia region of Ukraine. The objectives of this study is to develop approaches to the formalization of the spatial concept of potential danger and risk, develop methods of risk assessment, preparation of a database of research, use of GIS analysis to assess the distribution of risks.

2. Concept of Risk

2.1. Definition of Risk

There is a multitude of risk concepts and a large variety of taxonomies defining aspects like hazard, exposure or vulnerability. In this paper the risk is understood as the union of the probability and consequences of negative events, a quantitative measurement of risk with regard to its consequences (Bedford & Cooke 2001). Essential understanding of the risk gives rise to its quantitative, formal assessment based on some complex depending on where the risk is the probability of occurrence of certain adverse events. In the analysis of the risks and hazards of man-made need

to define what is meant by a negative event. Such event in most cases is an emergency situation, which may cause direct or indirect damage to people and to the loss of material resources.

In the classic sense of the probability is evaluated as a mathematical value that is calculated as a percentage. However, in real life calculation of such values in terms of a territorial linking is difficult. Therefore, in most cases use the approach of a relative rating scale, in which the risk for each point of space is determined in comparison to the other point. The second approach in the study of the risks of technological disaster is the account of the systems in the event of an accident. Typically, the most dangerous emergencies related to infrastructure objects, which are combined in a network. The accident of one of the network elements entails a chain reaction failure of other elements. In this case, you must consider the risk of an accident, not only on a single object, but in general, for the technological network.

The third approach to risk assessment is the anthropocentric approach, which is based on the understanding of risk as the potential number of victims of the disaster. Traditionally, this approach exists in civil defense and military affairs, and it moved to the modern methods for emergency response. The key concepts of this approach is the number of injured, the area and the radius of destruction, loss of life. In this case, the risk corresponds with vulnerability of territory and it is assessed as the number of people who potentially is in the area of accident or injury.

The integration of all three approaches evaluates the most complete spatial distribution of risks and hazards in the territory for make decisions on disaster prevention and control disaster management.

2.2. The Main Stages of GIS Research

The main stages of GIS research are:

- collection factual information about technological objects;
- development of structure and thematic classification information for the database, that is based on classification of emergencies;
- geocoding and structuring information to be used in a geographical database;
- creation of thematic layers of potentially dangerous technological objects;
- development inventory maps of potentially hazardous industrial objects in order to control and monitor the situation;

- creation of evaluation of risk maps and dangers technological disaster on the basis of the inventory maps using GIS modeling;
- conducting geographic analysis of the distribution of risks and hazards emergencies.

3. Development of a Database of Research

3.1. Sources of Database

The unified geographic database was created for research, which is based on official government data. The data of regional statistics, business register, environmental passport of Vinnytsia region (2011), cartographic sources and materials remote sensing of the Earth are the main information sources of research. The most important documents are state classifier of emergency (1998) and passports of potentially dangerous objects in regions of Ukraine (2010) that has an object-oriented structure.

Technological risks can be classified by type of threats to radiological, chemical, biological, technological fire and flood, explosions and traffic accidents. The industry classification of technological risks includes the main branches of industrial activity: energy (including nuclear), metallurgy, chemicals, food processing, machinery, forestry, water management and other industries.

The database structure was developed by combining objects on the basis the type of industry infrastructure and the type of technological threats.

Regional passport of potentially dangerous objects consists of the following structural elements:

- water supply: water extraction, water pumps, water supply, sewerage, drainage pumps, sewage treatment;
- buildings in emergency condition;
- storage of radioactive elements;
- explosive objects;
- storage areas of chemicals, waste, toxic chemicals;
- transformer substations;
- power plants;
- boilers and distribution stations;
- gas pipelines;

3.2. Basic Spatial Data and Geocoding of Thematic Information

For creating a geographical component of the database was used basic spatial data sets on Vinnytsia region. We have been used two major levels of data for the greatest accuracy and credibility in data modeling:

- scale 1:100 000 for the visualization of spatial data on the regional level;
- scale 1: 10 000 for more precise geocoding data and visualization in large settlements of Vinnytsia region.

Basic data of 1: 100 000 are layers of administrative-territorial division, the contours of settlements, roads, hydrography and vegetation. Basic data of 1: 10 000 are layers with the boundaries of settlements, blocks, streets, address space.

Developed a classification system of data enables to classify all objects, depending from the risk associated with them and the membership of an object of a specific technology group. Each object gets its own code, which relates it to a group of potentially hazardous objects. Implementation of a code system allows for more flexible work with spatial information and to select objects according to certain criteria.

The next step is geocoding of data. Geocoding occurs in two main ways: directly address binding or to link to the centroid of the object in the dataset. In the case of technological objects, most of which are anchored within the settlement or focus on them. Geocoding was performed using geocoding tools by software ArcGIS and by combining the tables with common names.

The geographic database was obtained as a result of the geocoding data, which has the highest possible the spatial accuracy at this stage of the study.

3.3. Attribute Data Classification

Attribute data are divided into five basic groups. The first group contains data that identifies the object in the group. This data is the unique number of the object in the database, a unique number in the aggregate number of similar data, a unique name of object or the organization.

The second group includes data about georeferencing of objects. This data includes the geographical coordinates of the object and its topological position. Under the topological position of the object understood its relation to other objects and the spatial position in the hierarchy of the administrative-territorial division, inside the settlement, district or region. Accordingly, column of database are filled coordinates, name of settlement, code classification of the administrative-territorial division of the settlement and the district, name of the administrative center of the district,

the name of the region of Ukraine. Such a construction of the database allows to quickly generalize the thematic information on any territorial level.

The third group includes typification of object that specifies the type or subtype of the object in the database. The object code, object code within the group, the name of a subgroup of the object is used as sign of type, which relates it to a group of potentially hazardous objects. In the case of pumping stations this may be splitting the group into subgroups in order of lifting water.

The fourth group is a quality set of attributes characterizing the state of the object. Qualitative characteristic is stored in the database as a character string and digital scale allows qualitative to estimate the potential state of danger. Primary qualitative characteristic of an object is its condition: in good or defective, the degree of reliability: low or high, the object's position in the system: central or peripheral.

The fifth group consists of quantitative data that can assess the quantity and species composition of the hazardous substances in the storage sites, the size of the zone of potential destruction or pollution in the accident, the number of objects or people in the zone of danger. Quantities will be presented as a dimensional value of the mass or volume of stored materials, geometric distance metrics, area or perimeter, the numerical parameters of the population or amount buildings.

3.4. Inventory Map of Potentially Dangerous Technological Objects

Development of the inventory maps of potentially dangerous technological objects can be in the form of a series of analytical maps that describe the state of individual group of objects, or complex maps, which integrates the totality of objects in a model of their geographical distribution. We chose the second approach a result which was obtained by the complex map of potentially dangerous objects on the territory of Vinnytsia region. Map Legend was developed on the principle of the transition from the overall situation to the individual objects on the local level.

The three basic scale with relevant thematic content: the scale of 1: 1 000 000, which corresponds to the regional level of the overview, scale 1: 100 000, which corresponds to the local level, the scale of 1: 10 000, which corresponds to the object level were used for ease of use of map data. Such a multiscale approach allows to evaluate the distribution of hazardous objects simultaneously on several territorial levels, to make quick management decisions to prevent disaster. (Figure 1).

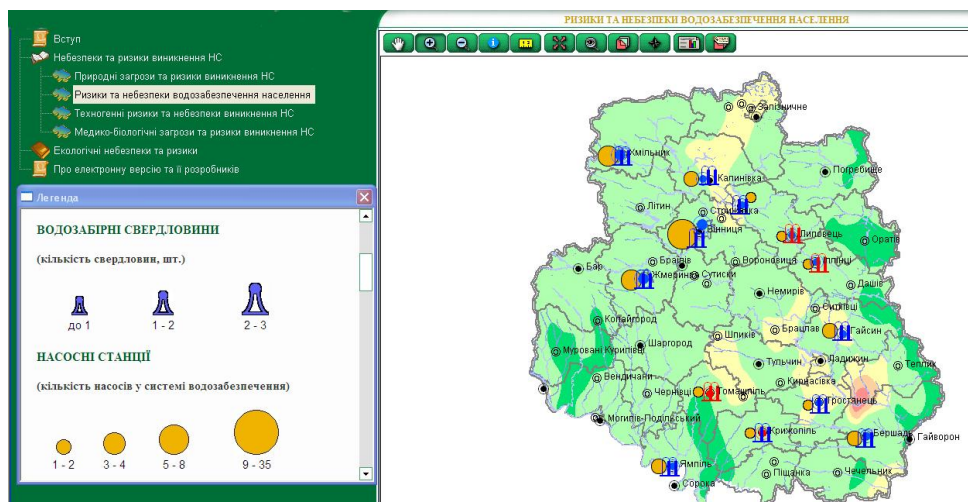


Figure 1. Inventory map of potentially hazardous industrial objects in Vinnytsia region.

The main features of the distribution of the technological objects on the territory, the most dangerous objects and their characteristics were shown at the regional level. A detailed assessment of infrastructure, especially its location, is given at the local level. Transport network, hydrography, the full list of settlements are added to layer of the administrative division. The most detailed assessment can be obtained at the object level, where every technological object, its surroundings and the potential consequences of an accident are considered detail.

4. Risk Assessment

4.1. Methodological Preconditions

Shift from the inventory to the assessment of hazards and risks is to consider the potential negative influence not only individual objects, but all their entirety at each point of the region. This influence can be expressed in the coverage of area that may be affected by the accident, the probability of a potential emergency, deterioration or violation of conditions of the residence of the population.

Several methodological preconditions were made for such an assessment:

- Each point has a specific own value of risks associated with technological disasters;
- Any current technological object represents a direct or indirect risk to the surrounding area;

- Disaster risk depends on the qualitative and quantitative characteristics of technological objects;
- Geographically risk emergency is represented as a zones of the negative effects of potential technological accident;
- At the place of intersection zones of negative effects the emergency risk increases in proportion to the number of technological objects.

4.2. GIS Analysis

The methodology for risk assessment of technological disasters was implemented on the basis these methodological prerequisite. The determining areas of potential negative impacts was conducted in the first stage. Traditionally, this technique is well developed in the analysis of possible chemical or radioactive damage. The zone of potential damage were defined as geometric buffers around the point of the object based on the quantity and type of stored hazardous materials. In the result the main tool for the GIS analysis was to build buffer zones. We have identified three types of buffers. Linear buffer zones have been built for transport infrastructure. The risk of accidents is measured in direct proportion to the volume of traffic. The buffers 1 km were built for international road, rail with double-track branch, gas pipelines. The buffers 500 m were built for national and regional roads, as well as single track and narrow gauge railways.

Circular buffers were built around a potentially dangerous technological objects, which may cause an accident with damage to the surrounding area. Radius of buffers was calculated based on data about stored materials. Another type of buffer was built around an object with a known amount of the population served. The radius of the buffer zone of risk is calculated as the value proportional to the number of the population served.

The next stage of the method is assigning a value of hazard for each buffer zone. It was decided to apply the method of ranking. Each zone was one of the four grades of danger according to the state of technological object. The selection four grades associated with the generally accepted division of chemicals and waste into four categories. But in contrast to chemical classification lower rank number corresponds to a lower risk. So for substances of class 1 dangerous rank will be equal to 4. This was done in order to conduct further sum of ranks of danger. Accordingly, buffers other objects have also received a rank on the scheme: 1 - good state, 2 - satisfactory, 3 - unsatisfactory, 4 - emergency.

In the final stage the imposition of buffer zones between them was conducted by method overlay analysis. It was formed by four basic risk

groups (Figure 2, 3): risks in transport; risks of water use; risks of fire and explosive objects; risks at chemical objects.

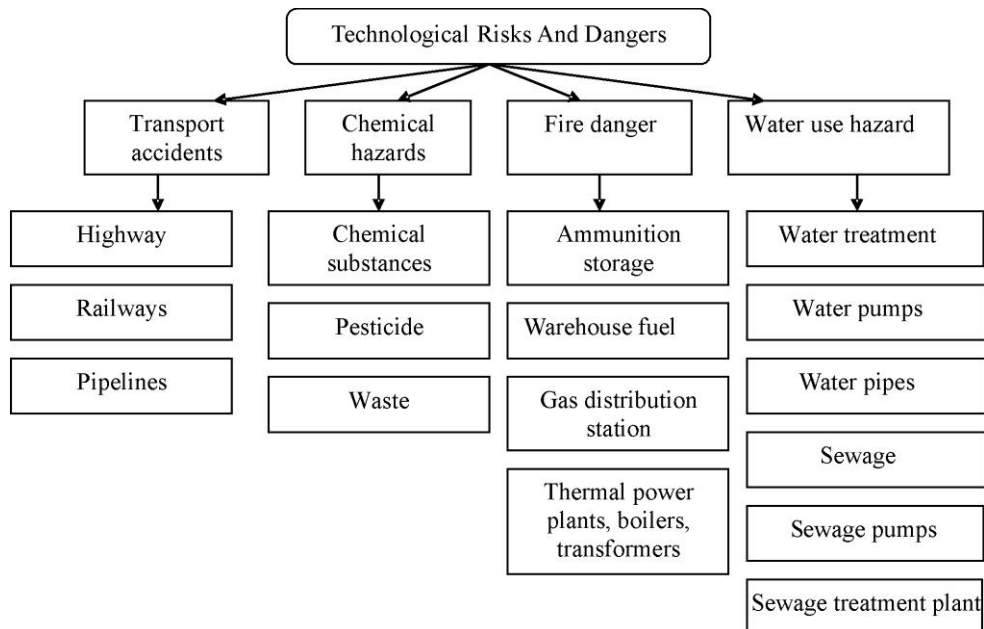


Figure 2. Groups of objects related with technological risks and dangers.

Integral assessment of technological risks was derived from the overlay analysis of all core groups by method «Union» of analysis tools in ArcGIS. The result was a vector layer consisting of 15 categories of potential risks, which was determined by the formula:

$$I = \sum_{n=1}^1 DrN, \text{ where}$$

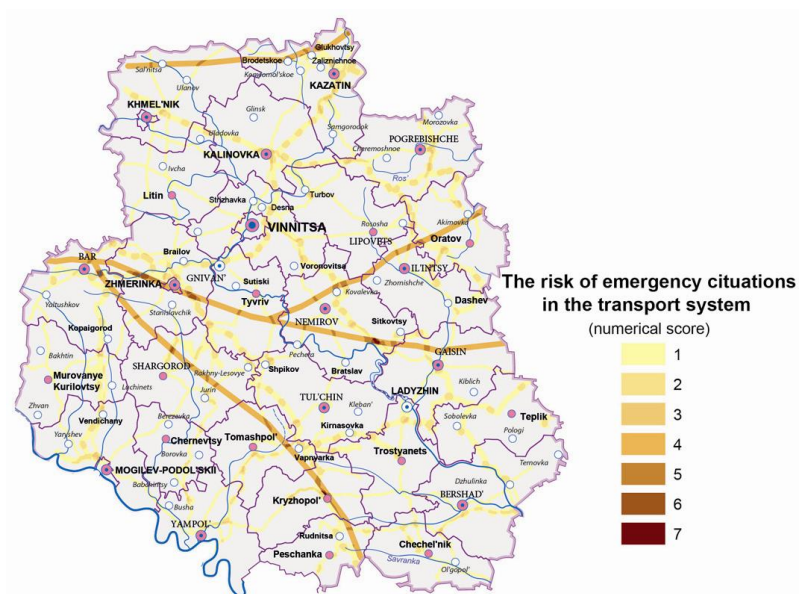
I - integral assessment

Dr - the rank of each of the buffer zone at that point.

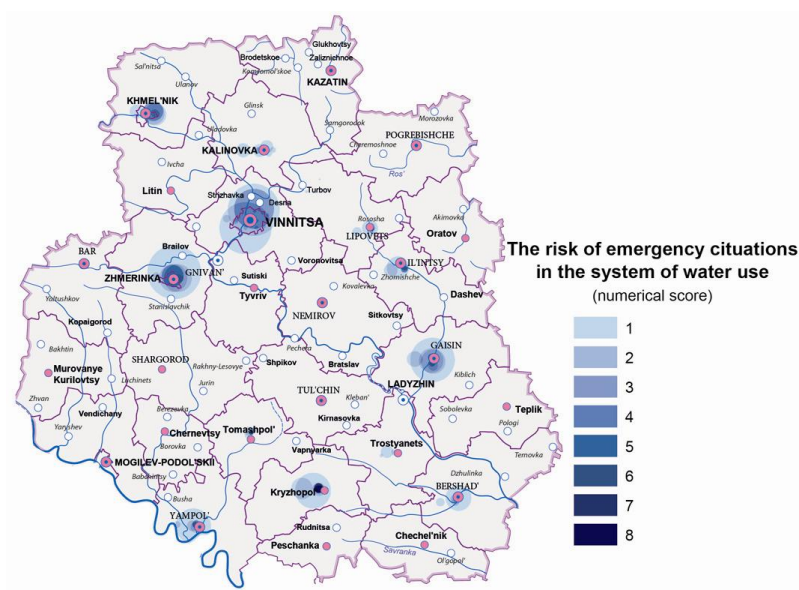
N - the presence of the intersection the buffer zone and the given point.

Each polygon layer characterized by a set of potential hazards that can be assessed by an attributive data.

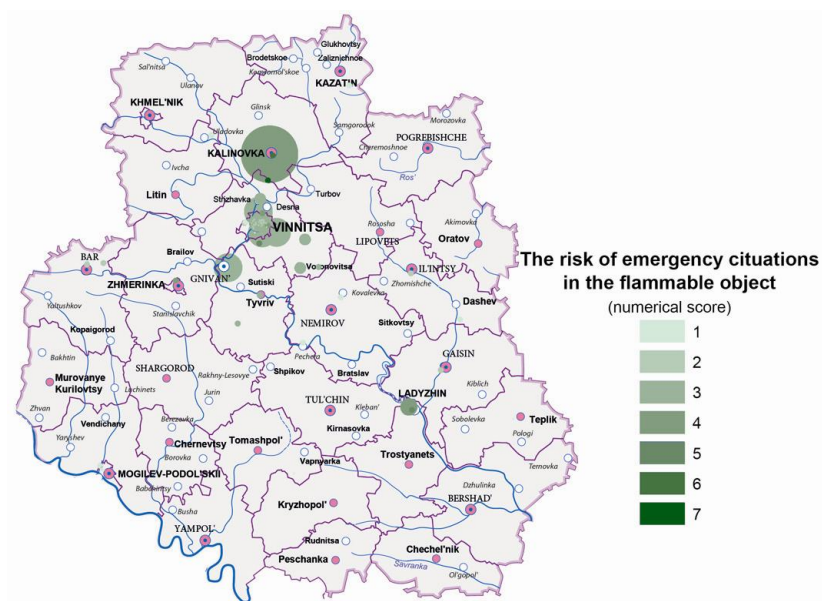
The quantitative background was obtained by method of classification that characterizes the territorial features of the distribution of technological risks in Vinnytsia region. (Figure 4). Comparison of these data with the population allows to evaluate the vulnerability relatively technological disasters.



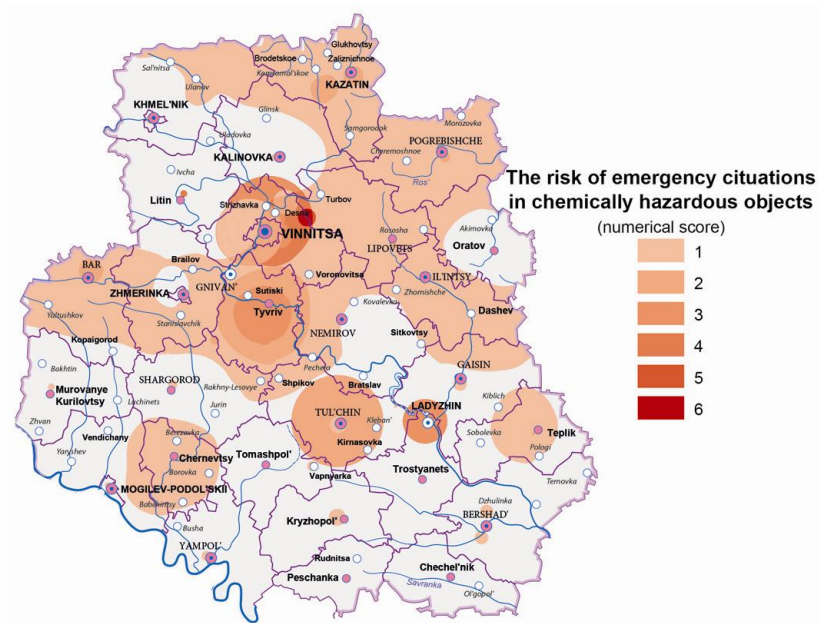
a.



b.



c.



d.

Figure 3. Basic risk groups of technological objects.

a. risks in transport; b. risks of water use; c. risks of fire and explosive objects; d. risks at chemical objects.

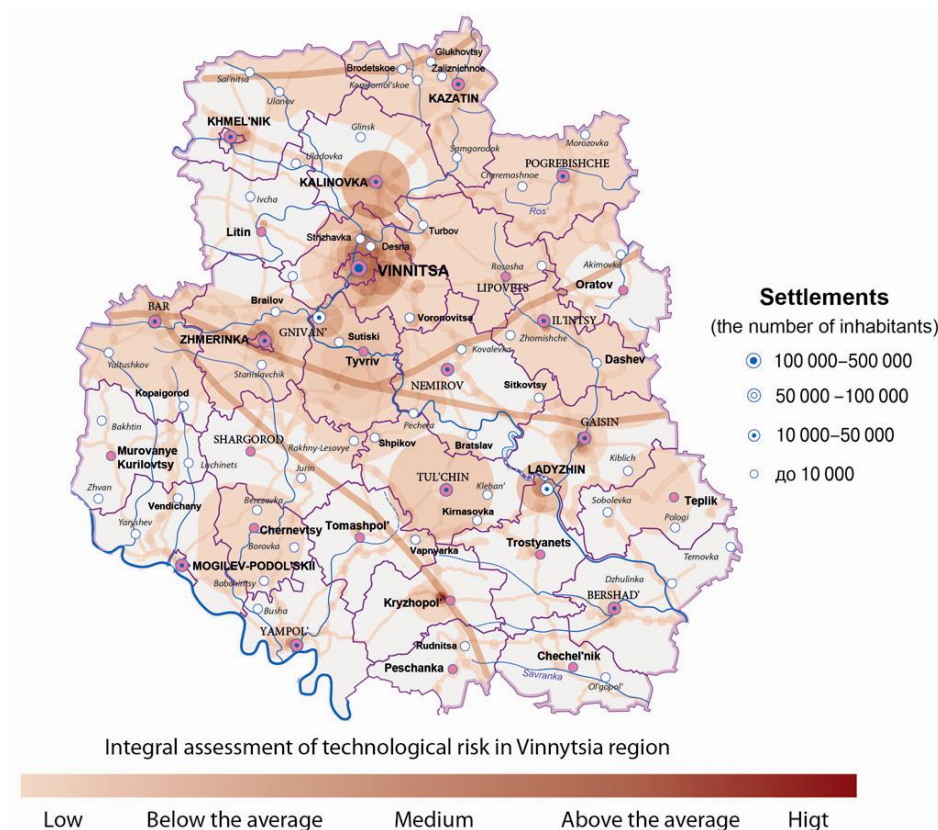


Figure 4. Integral assessment of technological risks in Vinnytsia region based on the analysis of the overlay buffer zones of potentially dangerous technological objects.

5. Common Spatial Patterns of Distribution Technological Risks in Vinnytsia Region

Analysis of the situation in the Vinnytsia region shows that technological hazards and risks are distributed territorially very unevenly. Network and nodal structure prevails in the distribution of risks. The transport infrastructure is a network structure that includes major road highways, railways, station infrastructure, pipeline. The major risks associated with the transport infrastructure is the possibility of road accidents and potential accidents involving the transport of dangerous goods. Especially these risk increases in major hubs and intersections several modes of transport. Lines of pipelines represent a significant risk. Nodal structure of the distribution of risks is connected with the concentration of potentially dangerous technological objects in the settlements. The regional center – city Vinnytsia

comes in the first place in the concentration of risks. This is explained by a high concentration of industrial and infrastructure services in the city. The cities of regional importance and small towns are characterized significant concentrations of risk where the risk of technological disaster is associated primarily with the water use and other objects of infrastructure. The places of organized storage of chemicals or explosive substances and landfills are the most dangerous for living people in this settlements.

6. Conclusions

Risk and hazard assessment of emergencies at different scale and territorial levels is the actual problem of national safety and protection of the population from natural and technological disasters. The need is to choose the methodological basis for understanding the risk of an emergency for evaluation research. In work the risk was defined as the possibility of certain negative events. Spatial approach to the definition of risk assessment allows widely use GIS and cartography methods in research.

The seven stages of risk assessment was allocated in the work, the main ones are: collection of information and forming a geographic database, creating of thematic layers for GIS, design of inventory maps, design assessment and prediction maps and layers of geodata, holding geographic risk analysis. The testing of the developed technique was conducted on the basis of data about potentially dangerous technological objects of Vinnytsia region. All objects have been grouped into four classes by hazard: transport accidents, chemical contamination, fire, water use. The zone of influence and hazard category of every of technological object was identified as a buffer zone around it, corresponding to the quantitative parameters of the object with attribute values of rank risk. The imposition of various risk zones through overlay analysis allowed to form a vector layer in which each polygon has an individual set of potential hazards and can be defined as the balance of risks and its integral indicators. The general distribution of risk assessment in the Vinnytsia region is subject to the laws of the network structure when the edges of the network are the largest traffic flows and nodes are settlements with a concentration of industrial and infrastructure objects.

References

Bartels C & van Beurden A (1998) Using geographic and cartographic principles for environmental assessment and risk mapping. *Journal of Hazardous Materials*, 61, 115-124.

- Bedford T and Cooke R M (2001) Probabilistic Risk Analysis: Foundations and Methods. Cambridge University Press, New York
- Borst D, Jung D, Murshed S, Werner U (2006) Development of a methodology to assess man-made risks in Germany. Nat. Hazards Earth Syst. Sci., 6, 779–802 www.nat-hazards-earth-syst-sci.net/6/779/2006/
- Choi Y J, Kim H K, Baek W P, Chang S H (2004) Hybrid accident simulation methodology using artificial neural networks for nuclear power plants[J]. Information Sciences, 160(1-4):207-224
- EEA (European Environment Agency) (2003) Mapping the impacts of recent natural disasters and technological accidents in Europe. Environmental Issue Report no. 35, Copenhagen, downloadable at <http://www.eea.europa.eu> [21/03/2006]
- ESPON (2005) The Spatial Effects and Management of Natural and Technological Hazards in Europe. Final report of the ESPON Project 1.3.1, 197 pp.
- Ferrier N, and Haque C E (2003) Hazards risk assessment methodology for emergency managers: A standardized framework for application. Nat. Hazards 28(2/3), 271–290
- Konecny M, Zlatanova S, Bandrova T (2010) Geographic Information and Cartography for Risk and Crisis Management: Towards Better Solutions. Springer-Verlag New York
- Lari S, Frattini P, Crosta G (2009) Integration of natural and technological risks in Lombardy, Italy. Nat. Hazards Earth Syst. Sci., 9, 2085–2106 www.nat-hazards-earth-syst-sci.net/9/2085/2009/
- Monmonier M (1997) Cartographies of danger: Mapping hazards in America. Chicago: University of Chicago Press. pp. 363.
- NRC (National Research Council) (2007) Tools and Methods for Estimating Populations at Risk. Washington, DC: National Academies Press
- Van Westen C J, Montoya L, and Boerboom L (2002) Multi-Hazard Risk Assessment using GIS in urban areas: A case study for the city of Turrialba, Costa-Rica. Proc. Regional workshop on Best Practise in Disaster Mitigation, Bali, 120–136
- Zhang D, Zhou L, Nunamaker Jr J F (2002) A Knowledge Management Framework for the Support of Decision Making in Humanitarian Assistance/Disaster Relief[J]. Knowledge and Information Systems, 4(3):370-385.
- Міністерство охорони навколишнього природного середовища України (2011) Вінницька область. Екологічний паспорт регіону, Київ, 114 с.
- Міністерство надзвичайних ситуацій та в справах захисту населення від наслідків Чорнобильської катастрофи (1998) Класифікатор надзвичайних ситуацій в Україні. Київ, 86 с.
- Головне управління МНС України в Вінницькій області (2010) Паспорт ризику виникнення надзвичайних ситуацій Вінницької області. Вінниця, 55 с.